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Associations between physical activity, sedentary time, sleep duration and daytime sleepiness in US adults

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ABSTRACT

Objective. To examine the associations between objectively measured physical activity (PA) or sedentary behavior and self-reported sleep duration or daytime sleepiness in a nationally representative sample of healthy US adults (N = 2128).

Methods. We report analyses of four aspects of sedentary behavior and PA derived from accelerometry data (minutes of sedentary time, activity counts/minute, Minutes of Moderate and Vigorous PA [MVPA], and MVPA in 10-minute bouts) versus self-report of sleep duration and frequency of daytime sleepiness from the 2005–2006 National Health and Nutrition Examination Survey.

Results. Age and sex dependence of associations between PA and sleep were observed. Aspects of PA were significantly lower in adults reporting more frequent daytime sleepiness in younger (20–39) and older (≥60) age groups, but not in middle-aged (40–59), respondents. In younger respondents, PA increased with sleep duration, but in middle aged and older respondents PA was either unrelated to sleep duration or lower in those reporting ≥8 h of sleep. Objectively measured sedentary time showed limited evidence of associations with sleep duration.

Conclusions. Further research delineating the relationships between sleep and PA is important because both activities have been implicated in diverse health outcomes as well as in the etiology of obesity.

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Introduction

Sleep and activities during time awake interact to influence many aspects of health, especially obesity and its consequences. Sleep duration is associated with diverse health indicators and outcomes, including mortality, elevated body mass index (BMI), hypertension, diabetes, and a variety of serum biomarkers related to energy balance and metabolism (e.g., Atkinson and Davenne, 2007; Buxton and Marcelli, 2010; Gangwisch et al., 2005; Hammond, 1964; Patel and Hu, 2008; Taheri et al., 2004). Physical activity (PA) is an important correlate of cardiometabolic risk, and increasing the activity level of the US population is a national health objective (Atkinson and Davenne, 2007; Patel and Hu, 2008; Sherrill et al., 1998; Youngstedt, 2005). Bidirectional effects linking sleep duration and PA have been reported, and may contribute to cross-sectional associations observed between sleep and obesity (Atkinson and Davenne, 2007; Lambiase et al., 2013). Exercise is widely believed to improve sleep duration and/or quality and some, but not all, randomized controlled trials have shown that exercise influences sleep regulation (Elavsky and McAuley, 2007; King et al., 1997; Youngstedt, 2005). However, the relationship between sleep and PA remains poorly understood, particularly at the population level and few studies include objective measurements of PA in the analysis of such bidirectional associations (Lambiase et al., 2013).

Prior population studies examining the association between exercise and sleep have relied on self-reported PA levels (e.g., Buxton and Marcelli, 2010; Gangwisch et al., 2005; Schoenborn and Adams, 2010). Self-reported PA can differ dramatically from objective measures (Troiano et al., 2008), and associations between serum energy balance biomarkers and objectively measured PA are stronger than those with self-reported PA (Atienza et al., 2011). Like self-reported PA, self-reported sleep duration is subject to cognitive challenges and other sources of measurement error (Kessler et al., 2010; Lewandowski et al., 2011). Nevertheless, many studies suggest that valid and reliable estimates of sleep duration and sleep quality can be collected via self report in adults (e.g., Beaudreau et al., 2012; Buysse et al., 2010; Spira et al., 2012) and children (reviewed in Spruyt and Gozal, 2011). Variable results of past studies on the bidirectional associations between sleep and PA could be clarified or resolved with better measurement (Atkinson and Davenne, 2007; Lambiase et al., 2013).

In this study, we report associations between several common aspects of objectively measured PA (Troiano et al., 2008), and both self-

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reported sleep duration and daytime sleepiness in healthy US adults from the 2005–2006 National Health and Nutrition Examination Survey (NHANES). Most past studies of sleep and PA have been based on self reported measures of physical activity (Basner et al., 2007; Chasens and Yang, 2012). A better understanding of associations between activities while awake and sleep could help lead to new hypotheses about their physiological and behavioral connections as well as foster new ideas about candidate interventions to improve sleep quality and increase levels of PA in increasingly sedentary populations.

Methods

This study used data on adults aged 20 years and older from the 2005–2006 National Health and Nutrition Examination Survey (NHANES), a cross-sectional study of a representative sample of the U.S. civilian noninstitutionalized population selected with a complex, multistage probability design. Data from this NHANES cycle were selected because it was the only cycle to include both self-reported sleep data (NHANES 2005-8) as well as objectively measured PA data (NHANES 2003-6). Age and health status were extracted as covariates for some analyses. Age groups were categorized (20–39, 40–59, 60+) as recommended by the NHANES analytic guidelines (http://www.cdc.gov/nchs/data/series/sr_02/sr02_161.pdf) and self-reported health (SRH) status was categorized as "Excellent," "Very Good," "Good," "Fair," or "Poor." Respondents reporting "Fair" or "Poor" health were excluded from the analysis as health status is likely correlated with both sleep characteristics and PA.

Data on sleep habits and disorders were collected by self-report responses to questions asked during the home interview portion of the NHANES survey. Interviewers learned about sleep duration by asking "How much sleep do you usually get at night, on weekdays or workdays?" Before public data release of the NHANES sleep questionnaire data file, for self-reported duration that included minutes, minutes of 30–59 were rounded up, and values greater than 12 h were categorized as 12 or more hours. Based on the distribution reported, sleep duration data were then categorized for analysis as <6, 6, 7, and ≥8 h per day. Small sample sizes precluded examination of respondents in more categories. Daytime sleepiness was estimated by asking "In the past month, how often did you feel excessively or overly sleepy during the day?". Responses were recorded within categories as never, rarely (1 time a month), sometimes (2–4 times a month), often (5–15 times a month), and almost always (16–30 times a month). Four categories of daytime sleepiness (never or rarely, sometimes, often, and almost always) were used as analytic categories in this study. Participants were excluded from analyses if they reported ever having been told by a doctor or other health professional that they had a sleep disorder.

Data on PA were collected from accelerometers worn by participants, starting from one day to as many as 4–6 weeks following sleep questionnaire administration. Participants examined in the NHANES Mobile Examination Center (MEC) were asked to wear an ActiGraph model 7164 accelerometer over the right hip during time awake and to remove the device while swimming or bathing. Data were recorded in 1 minute epochs for up to 7 days. Further details are available in Troiano et al. (2008). Participants with 10 or more hours of accelerometer wear time for 4+ days were included in analyses (Troiano et al., 2008).

The initial sample of 2005–2006 NHANES respondents age 20 or older was 4979. This sample was reduced sequentially based on specified exclusion criteria applied including; ineligible or no accelerometer data returned (dropped 1235), less than 4+ days of 10+ h accelerometer wear (dropped 731), self-reported sleep disorder (dropped 122), pregnant at time of exam (dropped 139), missing data on sleep duration or daytime sleepiness (dropped 8), reported fair/poor/missing health status (dropped 577), and measured BMI < 18.5 (dropped 39). The resulting analytic sample for this study includes N = 2128 respondents.

Different aspects of sedentary behavior and PA were obtained by extracting information about activity categories from the accelerometry data using established cutpoints (Matthews et al., 2008; Troiano et al., 2008). Activity categories included minutes of sedentary time (wear time min/day < 100 counts), the average daily accelerometer count rate (total counts/detected wear minutes), time spent in moderate-to-vigorous physical activity (MVPA; min/day ≥ 2020 counts), and MVPA time accumulated in modified 10-minute bouts (Bouted MVPA). Time spent in bouts was calculated by identifying periods that included at least eight out of ten consecutive minutes with ≥2020 counts/min (Troiano et al., 2008).

All analyses were carried out using SAS 9.1 (SAS Institute Inc., Cary, NC) and included sample weights and accounted for survey design features. Sample weights for respondents with valid accelerometer data were recalculated from the raw NHANES MEC sample weights (Troiano et al., 2008) to account for differential accelerometer wear compliance. We used multiple (for sleep duration) and logistic (for daytime sleepiness) regression models to examine associations between sleep, physical activity, and sedentary time. We first examined regression models for BMI, PA and sleep related variables (listed in Table 1) with age and sex as independent variables. Age and sex were significantly ($p < 0.05$) associated with sleep duration and daytime sleepiness and the age ∗ sex interaction was significant for sleep duration (Table 2). Additionally, PA related variables differed within and between sexes. Therefore, we chose to examine associations between PA and sleep, stratified by age and sex. Pairwise t-tests unadjusted for multiple comparisons within sex categories are reported to highlight variation in PA and sleep related to age. PA and sedentary time means were adjusted for SRH status and BMI of participants and either sleep duration or daytime sleepiness. Respondents reporting Fair/Poor health were excluded, but to account for potential effects of remaining variation in health and BMI, we included SRH and BMI in regression models used to estimated PA levels by sleep categories. Linear and quadratic trends in PA and sedentary time (measured across categories of sleep duration and daytime sleepiness) were assessed within sex and age groups for unadjusted data.

Results

The analytical sample included 682 adults aged 20–39, 725 adults aged 40–59, and 721 adults aged ≥60 years (Table 1). BMI, sedentary time, activity counts, MVPA, and bouted MVPA, had significant associations with age and sex (all model p values < 0.05 except for sex and BMI). Means comparisons within sex (Table 1) highlight the associations between age and these variables of interest.

Average sedentary minutes/day was not significantly different for men and women and greatest in the oldest age groups for both sexes. Average minutes of MVPA ranged from 9.8 (S.E. = 1.0) min/day in women aged ≥60 years to 38.1 (1.4) minutes/day in men aged 20–39 years. Overall, levels of MVPA were greater in men than women and decreased with age. Bouted MVPA minutes accounted for ~24% (in younger respondents) to ~40% of the total accumulated MVPA minutes/day in older respondents, which is likely attributable to the lower total accumulated MVPA minutes in older respondents.

Self-reported mean sleep duration ranged from 6.5 (0.1) h/day in men aged 40–59 years to 7.2 (0.1) h/day in men and women aged ≥60 years. Sleep characteristics were also associated with age and sex (Table 2), with a significant age ∗ sex interaction for sleep duration and significant effects of age and sex for daytime sleepiness. Men and the older respondents were less likely to report daytime sleepiness, and middle-aged men were more likely to report short sleep duration than older women (Table 2). The prevalence of reported daytime sleepiness was lowest among men and women aged ≥60 years. Women aged 40–59 years reported the highest prevalence of daytime sleepiness, with 50.2% feeling excessively sleepy during the day sometimes, often, or almost always in the past month.

Physical activity and sleep duration

Associations between activity and sleep duration differed by age group and sex (Table 3). Note that adjustment for daytime sleepiness did not qualitatively alter the trends in MVPA or other activity measures (not shown) across levels of sleep duration. Means comparisons presented here and below are unadjusted for multiple comparisons, resulting in an increased chance of false discover. In men, bouted MVPA was positively associated with sleep duration in the younger and middle aged respondents, but showed a curvilinear relationship in those aged ≥60. MVPA in one minute bouts also showed quadratic relations with sleep duration in middle aged and older men. Sedentary time decreased with sleep duration in older men or showed quadratic relationships (Significant in middle aged men). For example, men aged ≥60 reporting eight or more hours sleep per night had ~80 min per day less sedentary time.

Table 1
Descriptive statistics for age, anthropometrics, physical activity, and sleep by sex and age categories for our analytical sample of US adults from 2005 to 2006.

	Male			Female		
	20–39 years	40–59 years	≥60 year	20–39 years	40–59 years	≥60 years
N (Total = 2128)	367	362	375	315	363	346
Age[a] (years)	29.7 (0.4)	48.7 (0.4)	69.7 (0.5)	29.9 (0.3)	48.6 (0.3)	71.4 (0.5)
Height (cm)	177.2 (0.5)	176.8 (0.6)	173.9 (0.3)	163.6 (0.5)	163.3 (0.3)	160.0 (0.4)
Weight (kg)	85.3 (0.8)	89.9 (1.5)	85.6 (1.0)	73.9 (1.1)	75.8 (1.2)	70.7 (1.0)
BMI (kg/m^2)	27.1 (0.3) a	28.7 (0.4) b	28.2 (0.3)b	27.6 (0.5)a	28.5 (0.4)a	27.5 (0.3)a
Sedentary min/day	472.7 (6.7)a	485.8 (9.4)a	532.6 (10.1)b	463.9 (7.2)a	472.0 (7.5)a	523.6 (7.5)b
Activity counts/min	403.5 (6.8)a	381.7 (7.7)a	258.2 (7.1)b	335.7 (8.3)a	330.1 (7.0)a	214.5 (9.1)b
MVPA[b] min/day	38.1 (1.4)a	34.1 (1.2)b	16.2 (1.3)c	22.7 (1.0)a	21.8 (1.1)a	9.8 (1.0)b
Bouted MVPA min/day	9.2 (1.2)a	8.2 (0.6)a	5.7 (1.1)b	5.8 (0.8)a	6.9 (0.7)a	4.3 (0.7)b
Average sleep duration (hours)	7.0 (0.1)a	6.5 (0.1)b	7.2 (0.1)c	7.0 (0.1)a	6.9 (0.1)a	7.2 (0.1)a
Excessive daytime sleepiness (%, SE)						
Never or rarely	60.2 (2.5)	61.3 (3.2)	71.3 (2.7)	52.5 (2.3)	49.9 (3.0)	66.2 (2.2)
Sometimes	25.8 (2.7)	27.1 (1.9)	19.3 (2.9)	26.7 (2.5)	33.8 (2.7)	21.3 (2.0)
Often/almost always	14.0 (1.8)	11.6 (2.2)	9.4 (1.3)	20.8 (2.8)	16.3 (2.4)	12.5 (2.3)
Self-rated health						
Excellent	25.0 (2.8)	22.2 (2.4)	24.1 (3.7)	22.6 (2.2)	19.4 (1.9)	16.5 (1.7)
Very Good	38.1 (3.4)	34.3 (3.9)	34.7 (2.9)	39.8 (2.9)	39.8 (2.3)	38.8 (3.6)
Good	36.9 (2.6)	43.6 (3.1)	41.2 (4.1)	37.6 (3.2)	40.8 (2.2)	44.7 (3.2)

[a] Means and standard errors are given for all variables except daytime sleepiness and self rated health (%, SE). Means sharing the same letters are not significantly different within sex categories ($p < 0.05$).
[b] MVPA = Moderate and Vigorous Physical Activity.

Among women, significant linear or quadratic associations between MVPA minutes and sleep duration ($p < 0.05$) were observed in middle aged and older women and with activity counts in younger women. The highest (>24 min per day) amounts of MVPA were observed in younger and middle-aged women reporting ≥8 h of sleep per day sedentary minutes were not associated with sleep duration in middle-aged or older women, but showed a quadratic association with sleep duration in younger women due to lower amounts of sedentary time observed in women reporting 6 h of sleep per night.

Physical activity and daytime sleepiness

Physical activity by all measures was lower among respondents reporting more daytime sleepiness and these linear trends were significant in 7/9 comparisons for males and 6/9 comparisons for females (Table 4). Note that further adjustment for sleep duration did not qualitatively alter observed associations. For women aged 40–59 associations between PA and sleepiness were not significant, but differences in means were largely in the same direction. For all age and sex categories except men aged 40–59, sedentary minutes/day were highest among respondents reporting daytime sleepiness "often" or "almost always," but these differences and the linear trend tests were not significant.

Discussion

The three main results of this study are 1) the relationship between PA and self-reported sleep duration appeared to be age and sex dependent, 2) objectively measured PA was lower in respondents reporting more frequent daytime sleepiness, and 3) objectively measured sedentary time showed little or no association with either sleep duration or daytime sleepiness. These analyses complement recent studies examining the demographic correlates of PA and sedentary behavior in NHANES (Atienza et al., 2011; Belcher et al., 2010; Matthews et al., 2008; Troiano et al., 2008) and two recent analyses of sleep, sleep correlates, self-reported activities of daily living and step counts (Centers for Disease Control and Prevention, 2011; Chasens and Yang, 2012). The present study extends this work by examining several measures of PA and sedentary time obtained from accelerometry data rather than diverse activities of daily living, a common focus of past population studies of sleep (but see Basner et al., 2007; Chasens and Yang, 2012). The results could be of use in developing hypotheses about the determinants of sleep-PA associations and related physiological and health consequences. The findings suggest PA rather than sedentary time as a focus for research on the sleep-activity link and highlight the need to consider age and sex explicitly.

Previous studies have reported positive associations between self-reported exercise levels and sleep duration (Basner et al., 2007;

Table 2
Multiple logistic regression models for the association between self-reported sleep duration, daytime sleepiness, age and sex. Note the significant interaction term for sleep duration, but not for daytime sleepiness.

	Intercept	Sex (Ref. = Fem.) Male	Age (Ref. = Age >/= 60)		Sex * Age (Ref. – Female, Age >/= 60)	
			20–39	40–59	Male 20–39	Male 40–59
Sleep duration						
≤5	0.2 (0.1–0.3)	0.9 (0.5–1.6)	1.3 (0.5–1.6)	1.5 (0.8–2.8)	1.4 (0.7–2.7)	2.6 (1.3–5.5)
6	0.5 (0.3–0.7)	0.8 (0.5–1.4)	1.4 (0.8–2.1)	1.9 (1.2–3.0)	1.0 (0.5–1.9)	1.8 (1.0–3.4)
7	0.6 (0.4–0.8)	1.0 (0.6–1.8)	1.5 (0.9–2.4)	2.8 (1.8–4.2)	1.1 (0.5–2.3)	0.7 (0.3–1.6)
≥8	1.0 (Ref.)	1.0 (Ref.)	1.0 (Ref.)	1.0 (Ref.)	1.0 (Ref.)	
DF, Wald F, p-Value	–	–	–	–	6.0, 6.5, p = 0.0015	
Daytime sleepiness						
Never/rarely	5.0 (3.3–7.5)	1.6 (1.1–2.4)	0.5 (0.3–0.8)	0.6 (0.4–1.0)	–	–
Sometimes	1.7 (1.1–2.6)	1.3 (0.9–1.8)	0.8 (0.5–1.3)	1.2 (0.7–2.0)	–	–
Often/almost always	1.0 (Ref.)	1.0 (Ref.)	1.0 (Ref.)			
DF, Wald F, p-Value	–	2, 4.7, 0.026	4, 10.6, 0.0003	4.0, 0.44, p = 0.7796		

Table 3
Average daily physical activity and sedentary time across sleep duration categories by sex and age categories for our sample of US adults from 2005 to 2006.

Age	≤5 h	6 h	7 h	≥8 h	Trend[a]
	20–39 years				
A. Male sleep duration					
Sedentary min/day [b]	457.9 (16.3)a	483.1 (17.9)a	470.4 (19.2)a	474.4 (10.4)a	NS
Activity counts/min	404.6 (26.0)a	392.7 (20.9)a	409.3 (22.1)a	403.3 (10.1)a	NS
MVPA[c] min/day	35.5 (3.4)a	37.1 (3.0)a	39.9 (2.9)a	37.9 (2.1)a	NS
Bouted MVPA min/day	5.7 (2.2)a	7.1 (1.1)a	8.3 (1.4)a	12.5 (1.9)b	L
N	50	78	115	124	
Age	40–59 years				
Sedentary min/day	460.0 (18.4)a, b	493.6 (13.0)a, b	508.5 (12.3)a	465.9 (14.4)b	Q
Activity counts/min	380.1 (12.6)a	389.5 (15.3)a	378.4 (10.3)a	376.5 (15.2)a	NS
MVPA min/day	30.5 (2.7)a, b	36.9 (2.7)a, b	35.4 (1.7)a	31.3 (1.9)b	Q
Bouted MVPA min/day	4.1 (0.8)a	9.0 (1.1)b	9.8 (1.4)b	8.0 (0.8)b	L,Q
N	65	111	97	89	
Age	60+ years				
Sedentary min/day	602.5 (26.3)a	566.4 (20.8)a	506 (13.2)b	523.2 (9.1)a, b	L
Activity counts/min	214.5 (20.9)a	248.5 (17.7)a	294.0 (11.2)b	248.5 (13.0)a	NS
MVPA min/day	12.6 (3.0)a, b	16.0 (2.0)a, b	20.0 (1.8)a	14.6 (2.1)b	Q
Bouted MVPA min/day	3.1 (1.5)a	6.6 (1.8)a	7.4 (1.6)a	4.8 (1.5)a	NS
N	34	76	86	179	
B. Female sleep duration					
Sedentary min/day [b]	507.3 (18.7)a	435.6 (15.0)b	470.1 (8.6)a, c	465.7 (6.5)a, c	Q
Activity counts/min	284.7 (15.7)a	364.3 (14.4)b	325.7 (12.7)a, b	339.2 (13.6)b	L,Q
MVPA[c] min/day	18.3 (2.3)a	23.8 (2.1)a, b	21.3 (1.9)a, b	24.4 (2.1)b	NS
Bouted MVPA min/day	4.3 (1.3)a	6.0 (1.9)a	5.1 (1.4)a	6.7 (1.3)a	NS
N	50	78	115	124	
Age	40–59 years				
Sedentary min/day	473.7 (19.3)a, b	491.8 (15.6)a	475.1 (8.6)a, b	449.0 (14.0)b	NS
Activity counts/min	321.9 (27.6)a	312.5 (13.1)a	327.2 (9.5)a	352.7 (19.9)a	NS
MVPA min/day	20.6 (3.4)a	18.7 (2.0)a	22.2 (1.2)a	24.2 (2.8)a	NS
Bouted MVPA min/day	5.5 (1.9)a	6.0 (1.2)a	7.0 (0.9)a	8.0 (1.3)a	L
N	40	95	131	97	
Age	60+ years				
Sedentary min/day	532.1 (14.3)a	509.1 (14.4)a	529.2 (13.4)a	525.2 (10.3)a	NS
Activity counts/min	201.3 (20.3)a	236.3 (21.3)a	223.2 (15.7)a	202.3 (10.3)a	NS
MVPA min/day	6.5 (1.6)a	13.3 (2.8)a	10.2 (2.1)a	8.6 (1.1)a	Q
Bouted MVPA min/day	1.8 (1.1)a	6.1 (1.3)b	4.7 (1.4)a, b	3.7 (0.9)a, b	Q
N	36	75	93	142	

[a] L = Linear trend, $p < 0.05$, and Q = Quadratic trend, $p < 0.05$.
[b] Mean (SE), means comparisons based on pairwise contrasts within activity measures from models including self rated health and BMI. Sleep duration categories sharing a letter are not significantly different ($p < 0.05$).
[c] MVPA = Moderate and Vigorous Physical Activity.

Table 4
Average daily physical activity and sedentary time across daytime sleepiness categories by sex and age categories for our sample of US adults from 2005 to 2006.

	Males excessive daytime sleepiness				Females excessive daytime sleepiness			
	Never or rarely	Sometimes	Often/almost always		Never or rarely	Sometimes	Often/almost always	
Age	20–39 years			Linear trend***	20–39 years			Linear trend
Sedentary min/day*	465.5 (12.7)a	476.4 (15.7)a	497.3 (16.2)a	NS	454.2 (9.6)a	466.5 (10.0)a	485.3 (14.0)a	NS
Activity counts/min	418.7 (11.4)a	393.0 (16.4)a	357.4 (15.3)b	L	348.7 (8.6)a	341.7 (11.1)a	295.2 (18.5)b	L
MVPA** min/day	40.3 (1.9)a	36.8 (2.4)a, b	31.5 (2.0)b	L	24.3 (1.5)a	23.4 (1.7)a, b	17.9 (2.1)b	L
Bouted MVPA min/day	10.0 (1.5)a	9.9 (1.8)a	4.8 (1.3)b	L	6.6 (1.1)a	6.0 (1.6)a, b	3.5 (0.9)b	L
N	230	92	45		159	94	62	
Age	40–59 years				40–59 years			
Sedentary min/day	485.7 (9.9)a	499.0 (14.8)a	455.3 (26.9)a	NS	461.8 (9.8)a	480.3 (11.3)a	486.2 (15.0)a	NS
Activity Counts/min	379.6 (11.4)a	384.4 (10.1)a	386.4 (21.8)a	NS	346.9 (11.3)a	318.1 (10.4)a	303.2 (21.2)a	NS
MVPA min/day	33.5 (1.8)a	35.1 (2.0)a	34.6 (3.6)a	NS	23.7 (1.8)a	19.9 (1.2)a	19.8 (2.4)a	NS
Bouted MVPA min/day	8.2 (0.8)a	8.8 (1.6)a	6.5 (1.3)a	L	7.8 (1.0)a	5.6 (0.7)a	7.0 (1.5)a	NS
N	238	83	41		188	115	60	
Age	≥60 years				≥60 years			
Sedentary min/day	529.9 (10.4)a	521.3 (19.2)a	576.2 (33.4)a	NS	517.0 (10.6)a	522.5 (9.1)a	560.2 (19.9)a	NS
Activity Counts/min	264.7 (9.3)a	262.4 (19.4)a	199.6 (21.5)b	L	228.2 (13.1)a	195.6 (8.1)b	174.3 (16.7)b	L
MVPA min/day	17.3 (1.7)a	16.2 (1.9)a	7.7 (1.9)b	L	11.3 (1.5)a	7.2 (1.0)b	6.2 (1.4)b	L
Bouted MVPA min/day	6.3 (1.4)a	5.0 (1.3)a, b	1.8 (0.9)b	L	5.3 (0.9)a	2.5 (0.7)b	1.9 (0.8)b	L
N	266	73	36		232	73	41	

* Mean (SE), means comparisons based on pairwise contrasts within activity measures from models including self rated health and BMI. Daytime sleepiness categories sharing a letter are not significantly different ($p < 0.05$).
** MVPA = Moderate and Vigorous Physical Activity.
*** L = linear trend, $p < 0.05$, and Q = Quadratic trend, $p < 0.05$.

Elavsky and McAuley, 2007; King et al., 1997; Youngstedt, 2005). Our NHANES findings indicate the associations between sleep duration and PA measures are age and sex dependent. However, differences in PA by age and sex are larger and more consistent than differences in sleep duration. This could be a function of measurement method, since we examined objective measures of PA and self-reported measures of sleep. Given the large differences between accelerometry measured and self-reported PA (Troiano et al., 2008), the modality of PA measurement is also an important factor in interpreting findings on the association between PA and health measurements, including sleep duration and sleepiness. Strong reciprocal relationships between sleep, work and travel time could obscure associations between sleep duration and activities such as PA, which generally involve a smaller time commitment than sleep or work (Basner et al., 2007; Van Domelen et al., 2011). Disruption of normal sleep cycles and sleep duration by technology could also influence biological associations between PA and sleep (Atkinson and Davenne, 2007; Beccuti and Pannain, 2011). Together these factors may account for the age specific differences observed in this study in associations between PA and sleep. Further research is needed to understand how age and sex interact to influence associations between sleep duration and PA, and to determine whether improving sleep duration and quality increases the propensity to exercise, and/or whether engaging in exercise improves sleep duration and quality (Youngstedt, 2005).

Although observational studies have suggested that regular participation in PA is associated with improved sleep (Physical Activity Guidelines Advisory Committee, 2008), interventions aimed at improving sleep duration or quality through physical exercise have had mixed results, with some studies showing positive effects and others reporting little or no effect (Buman and King, 2010; Buman et al., 2011; King et al., 1997; Youngstedt, 2005). Greater efforts to determine specific demographic groups where interventions on PA or sleep result in correlated improvements in either trait would be of interest for interventions aimed at improved energy balance.

Multiple studies have reported that shorter and longer than optimal sleep are both associated with increased obesity, diabetes and other morbidities related to energy balance (Buxton and Marcelli, 2010; Gangwisch et al., 2005). Physical activity could mediate the effects of sleep on energy balance related health outcomes (Atkinson and Davenne, 2007; Basner et al., 2007; Gottlieb et al., 2005). In a recent review, shorter sleep duration was associated with increased obesity risk in five out of five longitudinal studies that controlled for self-reported PA (Patel and Hu, 2008). Reduced PA could be partly responsible (along with increased caloric intake) for weight gain observed in conjunction with shorter sleep duration. Fatigue and/or altered thermoregulation also could account for the influence of sleep duration on PA (Atkinson and Davenne, 2007; Patel and Hu, 2008). Progress in understanding the role of PA in mediating or moderating associations between sleep and health could be accelerated with better joint measurement of these two inter-related phenotypes.

Daytime sleepiness has been negatively associated with a number of measures of PA and physical function in older adults (Chasens et al., 2011) as well as obesity, even in the absence of sleep apnea (Beccuti and Pannain, 2011). In a recent analysis of the NHANES 2005–2006 data set that examined adults with pre-diabetes ($n = 958$), 17% of the sample reported often or always experiencing daytime sleepiness and 68% reported 7 or fewer hours per night of sleep (Chasens and Yang, 2012). The number of steps per day was negatively correlated with insomnia, but the authors did not report the association of steps per day with daytime sleepiness. Our data indicate that the frequency of daytime sleepiness is associated with reduced levels in at least one measure of PA, except in middle-aged women. The association of daytime sleepiness with PA is somewhat more consistent than with sleep duration, indicating that sleepiness and sleep duration may not be equivalent markers of sleep deficiency. Nevertheless, they could both be related to fatigue, a factor known to be associated with levels of PA (Puetz, 2006).

Fewer studies have explicitly examined the association between sedentary time and sleep (Basner et al., 2007). Past studies have reported that both sleep quality and sedentary behavior are associated with metabolic characteristics and metabolic syndrome (Gardiner et al., 2011; Hall et al., 2008; Healy et al., 2011; Kobayashi et al., 2011). Our focus on healthy adults in the present study may have obscured associations such as those found in studies of unhealthy participants. One very recent study examined the association between different levels of physical activity, sedentary time, sleep and cardiovascular disease risk biomarkers (Buman et al., 2014). However, it does not present the underlying associations between activity categories. The lack of associations between sedentary time and sleep duration (except in older men) observed here contrasts with a recent analysis of the ATUS survey which reports extensive associations between sleep duration and 17 of 18 time use categories examined including watching TV, sports, and 'socializing, relaxing leisure w/o TV' (Basner et al., 2007). One possibility is that self reported behaviors such as TV watching, which are typically reported as sedentary, may actually involve light activity. For example computer use or television viewing at home could be combined with childcare or household tasks. Objective measurement of sedentary time using waist-mounted Actigraph accelerometers, (based on periods in which the accelerometer is being worn, but in which the accelerometry counts are less than 100/min) is a strength of our study as well as other recent analyses of sedentary time using NHANES data (Buman et al., 2014; Koster et al., 2012).

Limitations and strengths

Because sleep and PA have been shown to influence one another (Youngstedt, 2005), care must be taken in interpreting the associations observed in this cross-sectional study. A major limitation of the present study involves the reliance on self-reported sleep duration and daytime sleepiness and the absence of additional objective measurements of sleep quality. This deficiency is currently being remedied in part through the inclusion of wrist-mounted ActiGraphs in NHANES 2011-14 intended to be worn during both awake and sleep time. Wrist mounted actigraphy can provide valid and reliable estimates of total sleep time and sleep efficiency (Weiss et al., 2010). A second potential weakness, but one that is difficult to evaluate involves the time lag in the NHANES data collection protocol between self report of sleep and accelerometer wear. This lag could attenuate associations between sleep and measured PA. Additionally this lag precludes examination of shorter term associations between sleep and PA. For example, a recent study of older (mean age 73) women reports that sleep efficiency was positively correlated with activity counts and MVPA on the following day (Lambiase et al., 2013). Key strengths of the present study include the availability of objectively measured PA and sedentary time and the large sample of adults spanning a wide age range. Future analyses could address employment status, a known correlate of PA in the NHANES data (Van Domelen et al., 2011) and its influence on associations between sleep and PA.

Conclusions

This study used NHANES 2005–2006 data for analyses of sleep duration, daytime sleepiness, and PA. It extends results of past studies by examining associations between sleep and objectively measured PA in a national survey of US adults. The principal findings are that the associations between PA and sleep duration and daytime sleepiness are age and sex dependent with PA often increasing as daytime sleepiness decreases and objectively measured sedentary time showing little or no association with sleep characteristics. These data point to the need for additional research to define the direction of these associations, i.e. if improving sleep quality or duration contributes to increasing PA, and conversely, if modifying PA levels has the ability to improve sleep characteristics. Delineating the relationships between sleep and PA is

important because both activities have been implicated in diverse health outcomes as well as in the etiology of obesity.

Conflict of interest

The authors declare there is no conflict of interest.

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